Cracking the AQ Code

ADEQ
Arizona Department of Environmental Quality
Air Quality Forecast Team

September 2017

Volume 3, Issue 6

Organized Thunderstorms in Arizona

By: The ADEQ Forecast Team (ADEQ Air Quality Meteorologists)

The monsoon brings all kinds of surprises to Arizona. From large, ominous walls of dust, to impressive shows of incessant lightning, to sudden torrents of rain, Arizonans receive a diverse array of weather phenomena this time of year. Even tornadoes are known to show up in rare instances. Yet, behind the scenes, there is often much more going on than we might realize. Did you know that thunderstorms sometimes combine with one another to create much larger systems? In this issue of *Cracking the AQ Code*, we will explore how thunderstorm activity can be organized and how this affects weather and air quality in Arizona. Of course, thunderstorm organization is not just limited to Arizona's monsoon season!

Figure 1. Thunderstorms building up in the distance to the north of Phoenix—a common sight during the monsoon season.

Photo Credit: Michael Graves

About "Cracking the AQ Code"

• • •

In an effort to further ADEQ's mission of protecting and enhancing the public health and environment, the Forecast Team has decided to produce periodic, in-depth articles about various topics related to weather and air quality.

Our hope is that these articles provide you with a better understanding of Arizona's air quality and environment. Together we can strive for a healthier future.

We hope you find them useful!

Upcoming Topics…

- Weather Chaos
- Measuring the World above Us

Publication No. N-17-06

Single-Cell Thunderstorms

Figure 2. A photograph of a single-cell thunderstorm taken from the Arizona Department of Environmental Quality's building, facing westward, toward the White Tanks Mountains. It is likely that these mountains helped to trigger this thunderstorm.

Photo Credit: Michael Graves

Now, let's start simple. At the most basic level of thunderstorm generation, we have what are called, "single-cell" thunderstorms (see Figure 2). Single-cell thunderstorms are, as their name implies, comprised of a single cumulonimbus cloud. Within this cloud is an "updraft," or a current of rising motion that feeds warm, moist air (fuel for the thunderstorm) into the cloud. Once rain starts to fall, a current of sinking motion called a "downdraft" develops in the cloud and eventually overcomes the updraft. This then initiates the storm's demise. Though usually small and short-lived, with a lifetime of about half an hour, single-cell thunderstorms can still pack a punch with heavy rain, hail, and/or microbursts (TSGC). Single-cell thunderstorms are fairly common in Arizona, especially during the monsoon season.

What does this mean for Air Quality?
Single-cell thunderstorms are localized. Locations under or very near a single-cell thunderstorm would likely have good or improving air quality as the thunderstorm blocks sunlight, hindering the ozone formation process, and disperses ozone with its winds. However, locations further away from the thunderstorm could potentially experience blowing dust as winds emanating from the thunderstorm (called "outflow winds") pick up and transport dust.

Organized Thunderstorms
Now that we are familiar with single-cell thunderstorms, we are ready to explore instances when multiple, single-cell thunderstorms organize together. When this happens, the system of thunderstorms is classified as a "mesoscale convective system." "Mesoscale" simply means that the physical size of the system is on the order of about five to five hundred miles in horizontal space (AMS). "Convective" refers to the fact that the thunderstorms are driven by "convection," or, the transfer of heat through vertical movements in the air (i.e. warm, moist air rises and cools in thunderstorms). We'll now look into various types of mesoscale convective systems often found in the Desert Southwest and see how they have an impact on our air quality.

Mesoscale Convective System Cluster
A mesoscale convective system cluster, or just MCS, is a large, irregularly-shaped mass of thunderstorm activity (i.e. heavy rainfall, frequent lightning, etc.) that is the product of the conglomeration of multiple separate thunderstorm cells (*Severe Storm Forecasting*, Vasquez).

Figure 3 shows a sequence of radar images revealing the development of an MCS over northern Pinal County. This particular storm system occurred on July 15 this year, during an active monsoon period. Thunderstorms that formed over the Mogollon Rim and the White Mountains made their way southwestward toward central Arizona. Once they reached each other, they merged together to create a broad area of moderate to heavy precipitation over northern Pinal County. Such a system can be a common occurrence during the monsoon, especially when there are numerous thunderstorms over an area.

What does this mean for air quality?
Despite potential hazards often associated with MCSs, such as flooding and lightning, MCSs typically improve air quality. Large areas of cloud cover, rain, and gusty winds essentially kill ozone formation and wash the air of all pollutants. But, just like a single-cell thunderstorm, outflow winds that emanate from an MCS could potentially result in blowing dust affecting areas far-removed from the system's influence.

Northwestern Mexico MCSs
Perhaps an even more common MCS that is characteristic of the monsoon is that of northwestern Mexico. In fact, it is estimated that this region is one of the places with the greatest frequency of MCSs in the world (Valdés-Manzanilla). During an active monsoon period, thunderstorms can form over the Sierra Madre Occidental mountain range in northwestern Mexico on a daily basis, typically moving to the

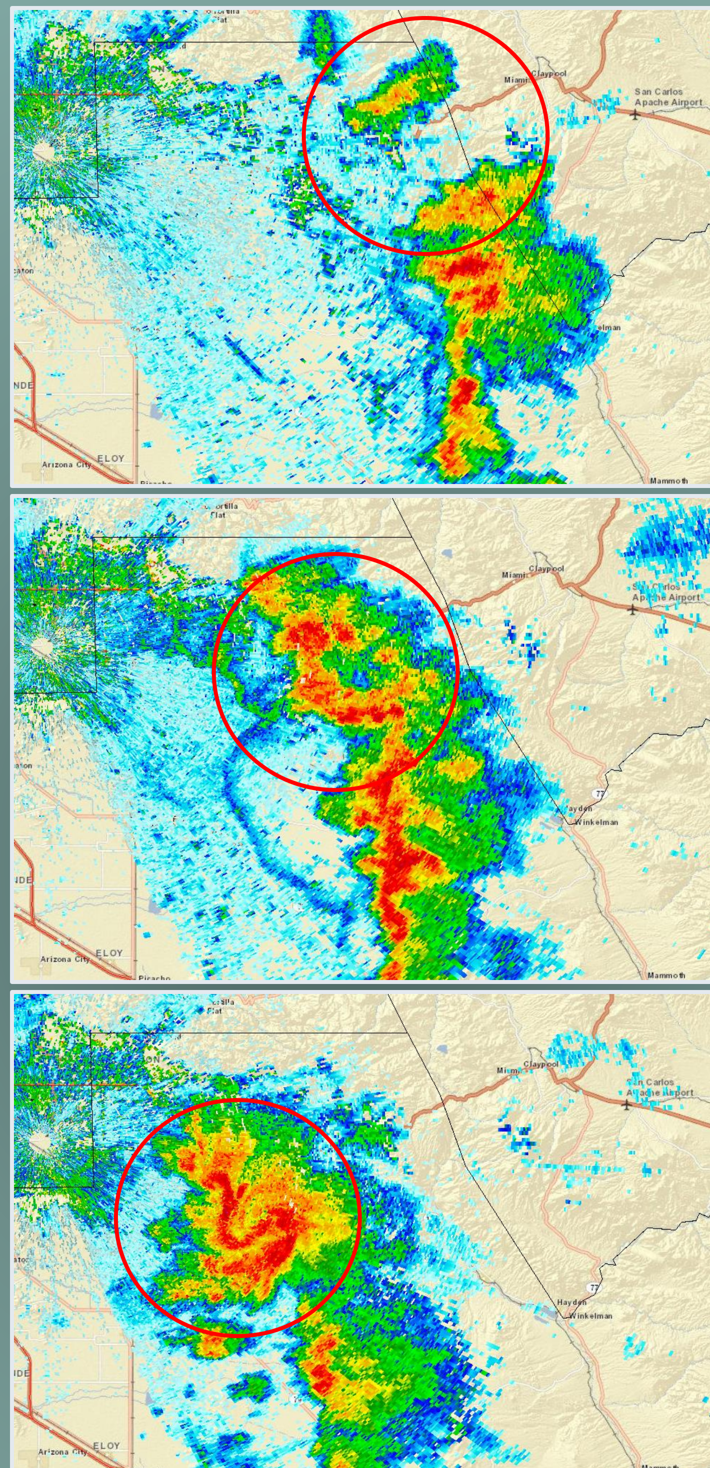


Figure 3. A sequence of radar images showing the development of a mesoscale convective system over northern Pinal County on July 15, 2017. Each image is approximately 30 minutes apart, from 4:10 PM to 5:15 PM. The red circles highlight the evolution of the system. In the last image, the system extends to slightly more than 20 miles from northwest to southeast.

Source: NOAA

Publication No. N-17-06

west or northwest. These thunderstorms can then merge into a larger system and form a broad area of cloud cover and precipitation. Such MCSs are often very recognizable by their circular shape evident on infrared satellite (Figure 4).

What does this mean for air quality?
Sometimes, as in the case of the system in Figure 4, MCSs from Mexico can trigger overnight thunderstorms in southern Arizona. Any rain associated with these storms would work to stabilize soils and lower the potential for dust. Also, cloud cover from these systems can expand into southern Arizona and be present in the morning the next day. If cloud cover sticks around long enough in the morning, it could delay the timing of thunderstorm development in the area, which could then have ramifications on the potential for thunderstorm activity in the Phoenix area later in the day. This, of course, would affect the air quality forecast for Phoenix. As we will see, MCSs even further south can also influence air quality in Arizona.

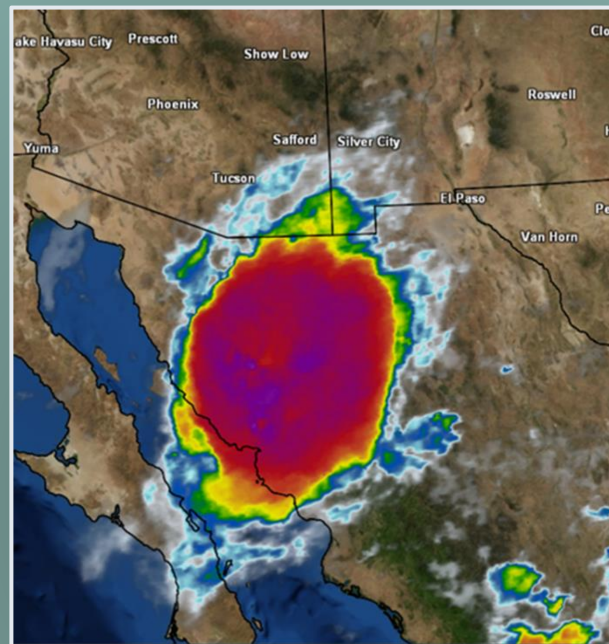


Figure 4. An infrared satellite image of a mesoscale convective system (MCS) over the Sierra Madre Occidental mountains in northwestern Mexico. The colors represent cloud top temperatures, where the deep reds and purples represent the coldest temperatures. The colder the cloud top temperatures, the higher the clouds reach into the atmosphere. From this image, we can see that almost all of the MCS has very cold cloud tops and therefore, very tall clouds. Notice the very circular appearance of the system.

Source: GREarth

Nogales Dust Event
During the monsoon season, Nogales, Arizona typically experiences superb air quality. This is largely due to almost daily bouts of thunderstorms providing abundant rainfall and dispersion to the area. On occasion though, Nogales can be the recipient of blowing dust caused by organized thunderstorm systems originating from Mexico.

One such event occurred on July 25, 2014. At 7:30 AM on the 24th, a mature MCS was situated over the southern tip of the Baja Peninsula (Figure 5, left). This system eventually hurled outflow winds up the Gulf of California, which transported tropical, warm moist air into northwestern Mexico. Unsurprisingly, thunderstorms formed over northwestern Mexico in the afternoon (Figure 5, right).

Want to learn more about other weather and air quality topics in Arizona?
Click to explore our full *Cracking the AQ Code* archive!

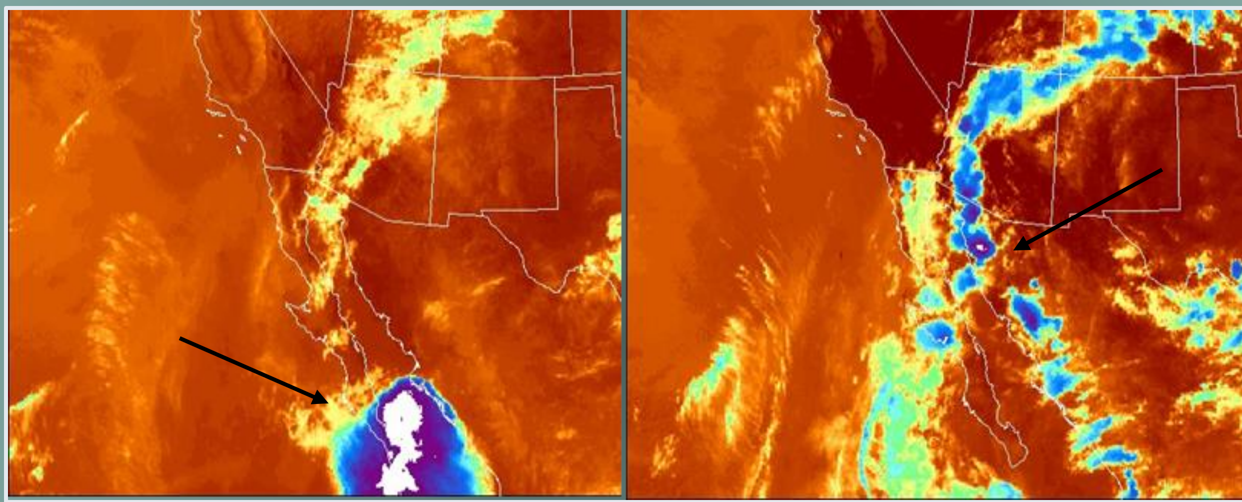


Figure 5. Color-enhanced infrared satellite images of the U.S. Southwest and northwestern Mexico taken at 7:30 AM July 24, 2014 (left) and 5:45 PM the same day (right). The black arrow in the left image points to the MCS over the Baja Peninsula. The black arrow in the right image points to resulting thunderstorms over northwestern Mexico that were eventually responsible for pushing dust into Nogales.

Source: UCAR Image Archive

These thunderstorms then sent out strong winds northward across the desert, toward Arizona. By early morning on the 25th, dust arrived in Nogales (Tucson News Now). At the Nogales International Airport, visibility was knocked down to only five miles between 6:00 AM and 7:00 AM. This ultimately resulted in a rare, summertime PM_{10} exceedance for Nogales (Figure 6).

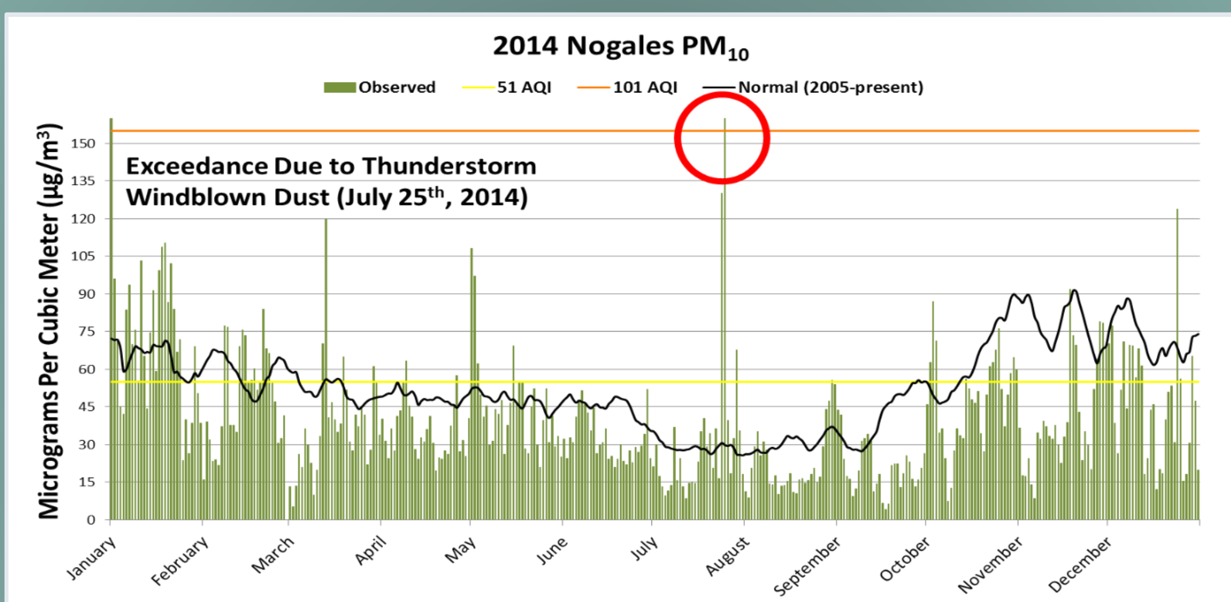


Figure 6. A graph showing the observed daily average PM_{10} concentrations in Nogales, Arizona for 2014. The horizontal orange line represents the federal PM_{10} standard. Notice the remarkably large jump in PM_{10} levels toward the end of July (highlighted by the red circle), which corresponds to the July 25, 2014 dust event. The PM_{10} health standard was only exceeded twice in 2014: on New Year's Day, which is typical, and on July 25, which is rare.

Squall Lines

Another type of MCS that can be found in Arizona is a "squall line." A squall line is simply a line of thunderstorms that can either be a continuous line or have breaks. What sets a squall line apart from other MCSs is that it has a much larger length compared to its width (AMS).

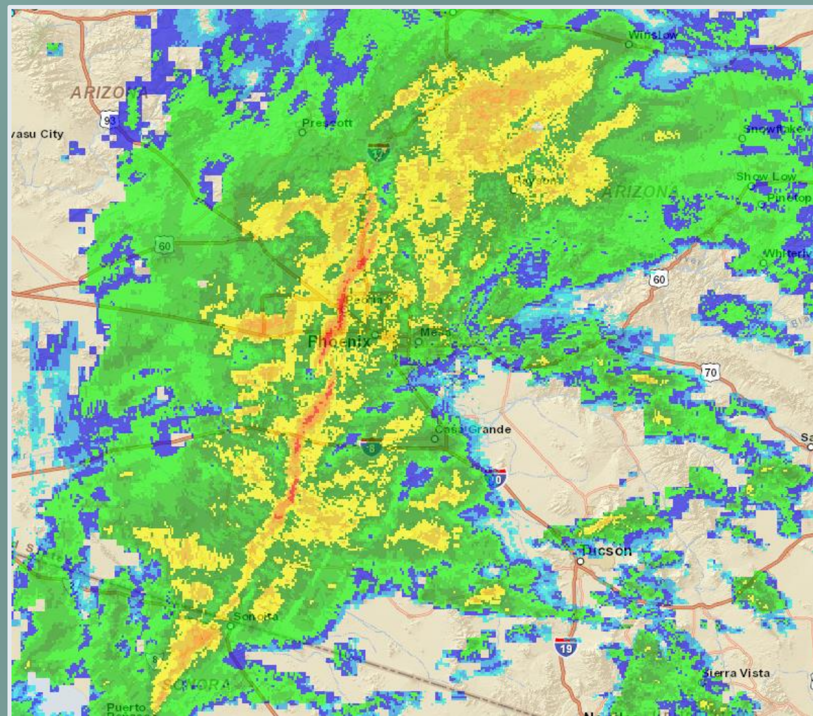
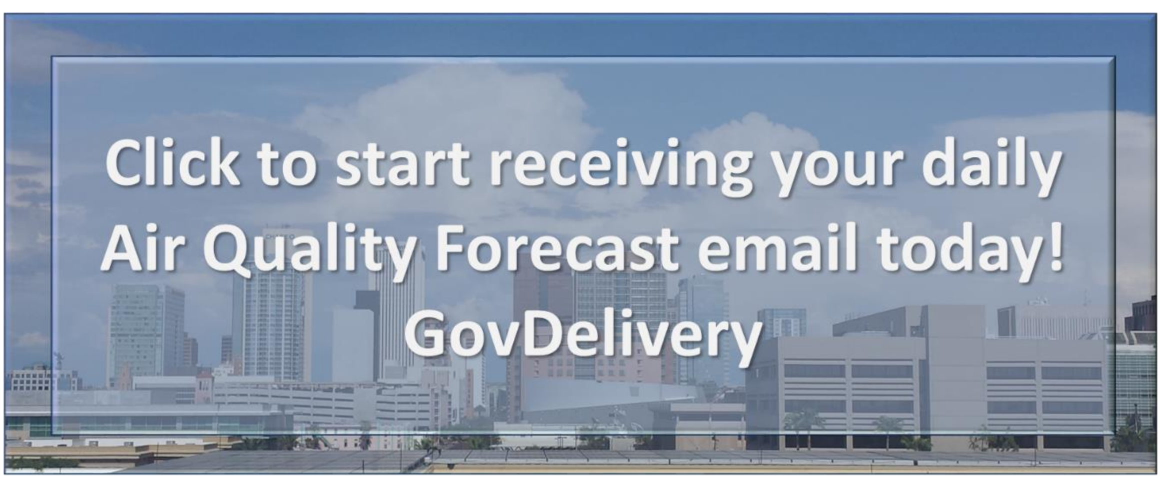


Figure 7. A radar image of a strong squall line over much of central Arizona on January 21, 2010, associated with a cold front. This system resulted in record amounts of rainfall and even a tornado near Phoenix (Freedman).

Source: NOAA

During the colder months, a squall line is typically the result of a strong cold front sweeping through the state, like in Figure 7. As the cold front moves through, it pushes moist air upwards and triggers thunderstorms along the length of its leading edge.

During the monsoon season, a line of thunderstorms can sometimes organize on its own, given the right atmospheric conditions. But, different from the traditional, cold frontal squall line, a monsoonal squall line is driven by the outflow winds of its thunderstorms. Figure 8 shows an example of a monsoonal squall line from August 2016, moving through central Arizona toward the southwest. As outflow winds move out ahead of the thunderstorms (left image, made visible on radar due to the dust and other particles they pick up), they trigger a new line of thunderstorms downwind of the original line. This new line eventually produces its own outflow winds, which in turn trigger new thunderstorms further downwind. Through this "propagation" process, the line of thunderstorms continues to advance (right image) until the environment becomes unfavorable for additional thunderstorm development.



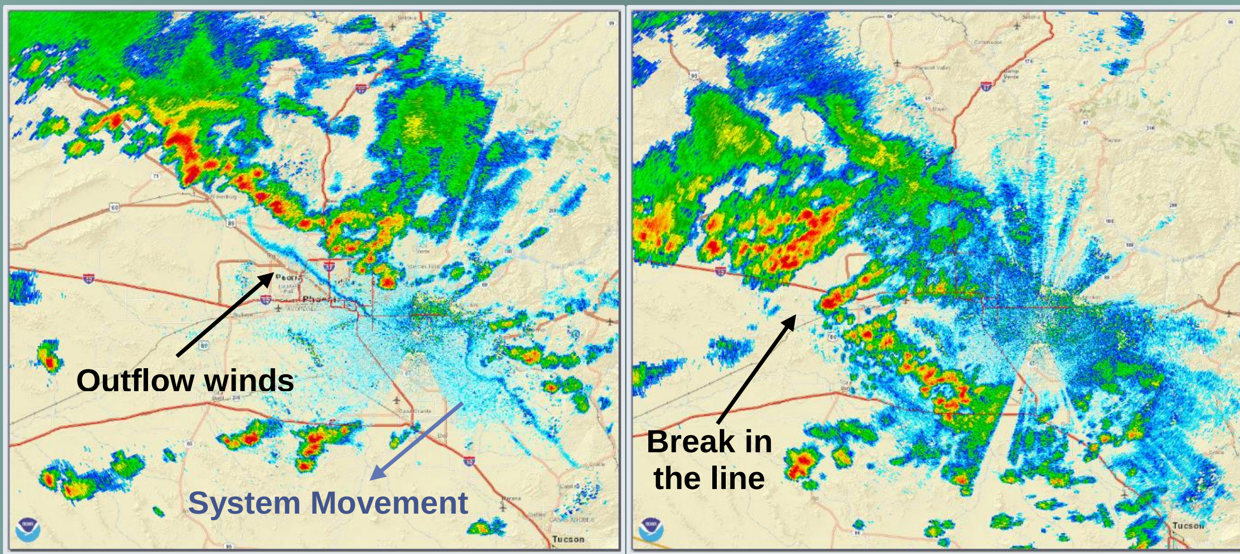


Figure 8. Two radar images showing the advancement of a line of monsoonal thunderstorms from northeast to southwest across central Arizona, on August 20, 2016. The left image was taken at 6:00 PM, the right at 7:50 PM. In the left image, the black arrow points to the line of outflow winds (thin, blue line) that eventually triggered new thunderstorms. In the right image, the black arrow points to a break in the thunderstorm line. Between these images, the line of thunderstorms travelled approximately 40-50 miles toward the southwest.

Source: NOAA

What does this mean for air quality?

Much like MCS clusters, cold frontal squall lines typically bring in good air quality due to their widespread rain. In particular, they are welcome during the colder months because $PM_{2.5}$ (fine particulates) levels are usually elevated on a daily basis, as a result of increased fireplace usage and a stronger inversion. This is true for both Phoenix and Nogales. A cold frontal squall line would provide rain to wash $PM_{2.5}$ out of the air.

Monsoonal squall lines, on the other hand, can lead to both poorer air quality and improved air quality. Outflow winds often result in blowing dust as they pick up and push dust out ahead of the thunderstorm line, as in the left image in Figure 8. Rain then soon follows the outflow winds in many places, putting an end to the dust and clearing out the air. However, it is certainly possible for locations to receive dust but no rain. This would happen if there were breaks in the thunderstorm line, as in the fairly large break indicated in the right image in Figure 8.

The Big Picture

When it comes to thunderstorms, what we see out the window does not always give the full story. Sure, we see the effects—clouds, rain, lightning, winds—but the big picture is not always immediately apparent. Fortunately, we have tools like radar and satellite imagery, which help reveal to us what thunderstorms are *really* doing. This is good news for air quality forecasting—better knowledge of thunderstorms leads to better forecasts!

We hope you enjoyed getting a "behind the scenes" look at thunderstorms during the monsoon season!

Sincerely,

The ADEQ Forecast Team

ForecastTeam@azdeq.gov

If you haven't already, click HERE to start receiving your Daily Air Quality Forecasts (Phoenix, Yuma, Nogales)

In case you missed the previous Issues…

March 2017: [Tools of the Air Quality Forecasting Trade Part 3: Satellite Imagery]
May 2017: [You Ask, We Answer: Part 1]
June 2017:[Patterns in Phoenix Air Pollution]
July 2017: [Tools of the Air Quality Forecasting Trade Part 4: Weather Forecast Models]
For Full Archive (2015-2017): [Click Here]

Here's a look at what we'll be discussing in the near future…

-Weather Chaos
-Measuring the World above Us

Arizona Department of Environmental Quality
Air Quality Forecast Team

1110 W. Washington Street   Phoenix, Arizona 85007   ForecastTeam@azdeq.gov